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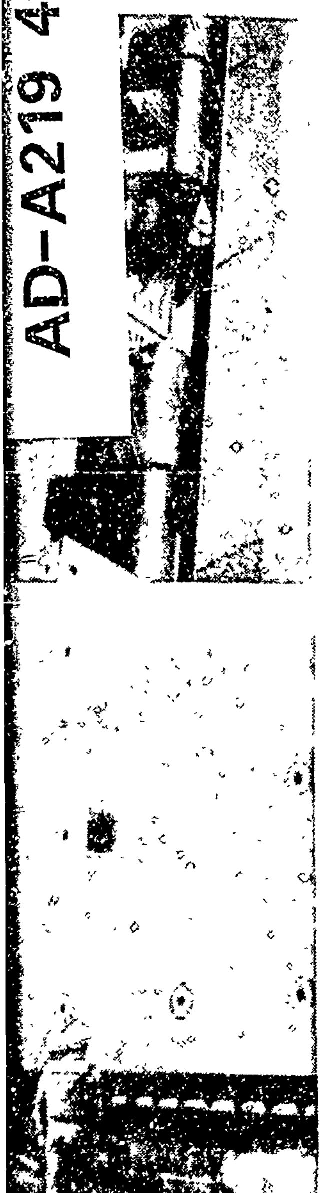

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MECHANICAL PROPERTIES AND CORROSION BEHAVIOR OF STAINLESS STEELS FOR LOCKS, DAMS, AND HYDROELECTRIC PLANT APPLICATIONS

by

Ashok Kumar and Ali A. Odeh

Construction Engineering Research Laboratory

DEPARTMENT OF THE ARMY
US Army Corps of Engineers
PO Box 4005, Champaign, Illinois 61820-1305

and

James R. Myers

JRM Associates
4198 Merlyn Drive
Franklin, OH 45005

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HY	Hydraulics	OM	Operations Management
CO	Coastal		

COVER PHOTOS:

TOP - Mooring bitt at Belleville Lock and Dam.

BOTTOM - Ceramic anodes at Pike Island Lock and Dam.

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Carbon steels and low-alloy carbon steels have been the primary source for materials used to construct locks, dams, and hydroelectric plant structures. Some components for these facilities have also been fabricated from 300-series austenitic stainless steels and the martensitic grades of 400-series stainless steels. Advanced technology alloys that have better corrosion resistance and higher strength than alloys developed earlier can be advantageous for water resource projects. This report presents typical

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and JRM Associates

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4198 Merlyn Drive
Franklin, OH 45005

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mechanical property data, briefly discusses corrosion behavior, and provides general guidelines regarding the use of stainless steels for locks, dams, and hydroelectric plant applications. Carefully selected and properly specified stainless steels are viable options for construction and can result in reduced maintenance costs. Two case studies for rollers and seals for tractor type dam gates are presented to demonstrate the advantages of using stainless steels for Civil Works projects. (SDW)

PREFACE

The study reported herein was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), as a part of the Electrical and Mechanical Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. The work was performed under Civil Works Research Work Unit 32338, "Corrosion Resistant Materials for Civil Works Structures" for which Dr. Ashok Kumar is the Principal Investigator. R. Pletka is the REMR Technical Monitor for this work.

Mr. Jesse A. Pfeiffer, Jr. is the REMR coordinator at the Directorate of Research and Development, HQUSACE; Mr. James E. Crews and Dr. Tony C. Liu serve as the REMR Overview Committee; Mr. William F. McCleese (CECW-OM), US Army Waterways Experiment Station (WES), is the REMR Program Manager. Dr. Ashok Kumar is the Problem Area Leader for the Electrical and Mechanical Problem Area.

This work was conducted by the US Army Construction Engineering Research Laboratory (USACERL) and Mr. James R. Myers, JRM Associates, Franklin, OH, under the general supervision of Dr. R. Quattrone, Chief of the Engineering and Materials Division (EM). The Technical Editor was Gloria J. Wienke, Information Management Office.

COL Carl O. Magnell was Commander and Director of USACERL, and Dr. L. R. Shaffer was Technical Director.

CONTENTS

MECHANICAL PROPERTIES AND CORROSION BEHAVIOR OF STAINLESS STEELS FOR LOCKS, DAMS, AND HYDROELECTRIC PLANT APPLICATIONS

PART I: INTRODUCTION

Background

1. Carbon steels and low-alloy steels have been the primary source for materials used to construct locks, dams, and hydroelectric plants. To a much lesser extent, components for these facilities traditionally have been fabricated from 400-series martensitic stainless steels (e.g., Types 410 and 416) and 300-series austenitic stainless steels (e.g., Types 302, 303, 304, 308, and 316). Although the 300-series stainless steels normally have excellent corrosion resistance in most freshwater environments (Table 1, Kamp and Schmitt 1966) their yield strengths (about 35,000 psi in the annealed condition) are somewhat low for many applications. Further, at a number of locks and dams, bolts and nuts fabricated from the same 300-series material have exhibited serious galling problems in the threaded area. The 300-series stainless steels (including Type 316, which is formulated with a small amount of molybdenum added to resist pitting attack) also have a tendency to pit in waters containing more than about 1000 parts per million (ppm) chloride. They are also susceptible to oxygen differential, concentration-cell corrosion under deposits and in crevices. Fortunately, the austenitic grades of stainless steel do not experience chloride-induced, stress-corrosion cracking at temperatures less than about 150° F (Pecknar and Bernstein 1977). They also exhibit excellent resistance to freshwater erosion corrosion.

2. The yield strength limitations of the 300-series stainless steels for Civil Works projects were originally overcome by using heat-treatable, 400-series stainless steels. Unfortunately, these alloys often do not exhibit the desired corrosion resistance. This is understandable because the metallurgy required to create a martensitic stainless steel allows only limited amounts of chromium (generally, an upper limit of about 14 percent) to be added to these alloys. The martensitic grades of stainless steel have a tendency to pit (Table 1), galvanically corrode, crack due to stress corrosion, and suffer concentration-cell corrosion in many fresh waters. In some cases (Fontana and Greene 1967), heat treated, 400-series stainless

steels have failed due to hydrogen-induced cracking because the components were only slightly overprotected by the cathodic protection systems designed to mitigate corrosion.

3. Traditional stainless steels have certain mechanical property and corrosion behavior limitations for lock, dam, and hydroelectric plant applications. However, carefully selected and properly specified stainless steels, especially some of the newer alloys, can be viably and cost-effectively used. These steels can reduce maintenance costs and improve the availability of equipment and facilities without significant concern for the various forms of deterioration that have been associated with them (e.g., crevice corrosion, intergranular attack, stress-corrosion cracking, hydrogen embrittlement, pitting, wear and galling, and galvanic corrosion).

Objective

4. The objective of this work is to present typical mechanical property data, briefly discuss corrosion behavior, and provide general guidelines regarding the use of stainless steels for locks, dams, and hydroelectric plant applications. The unique properties of stainless steels are shown in this report.

Approach

5. Researchers selected 14 stainless steels that may reduce maintenance costs and are becoming more available for Civil Works applications. These are: the wrought austenitic alloys NITRONIC 60* and Types 302, 303, 304, 308, and 316; the wrought martensitic alloys Types 410, 416, and 431; the wrought martensitic PH (precipitation-hardening) alloys 17-4PH and Custom 450*; the wrought semiaustenitic PH alloy 17-7PH; the cast martensitic alloy CA-6NM; and the cast austenitic-ferritic alloy CF-8.

*Nitronic 60 is a brand name of Carpenter Technology, Carpenter Steel Division, Reading, Pennsylvania, 19612.
*Custom 450 is a brand name of Carpenter Technology, Carpenter Steel Division, Reading, Pennsylvania, 19612.

6. Researchers discussed these stainless steels with U.S. Army Corps of Engineers personnel and obtained additional information from various guide specifications and as-built drawings.

PART II: COMPOSITION AND PROPERTIES

7. Nominal chemical compositions for the selected atainless steel alloys and their typical mechanical properties are included in Tables 2 and 3, respectively. Austenitic grades of stainless steel cannot be strengthened by heat treatment; they can only be strengthened by cold working. Martensitic and the PH grades of stainless steel can be heat treated to microstructural conditions that provide a wide range of available mechanical properties.

8. Generally, the austenitic grades of stainless steel (e.g., NITRONIC 60 and the 300-series) have better overall corrosion resistance than the other alloys identified in Tables 2 and 3. Typical corrosion resistance, however, depends on heat treatment. For example, the corrosion resistance of 17-7PH stainless steel in both Conditions TH1050 and RH950 is superior to that of the heat-treatable, martensitic alloys. In Condition CH900, the general corrosion resistance of 17-7PH is comparable to that of Types 302 and 304 (Armco, Inc. 1984b). The corrosion resistance of Condition A 17-4PH stainless steel and the alloy when heat treated to its lower (albeit, still relatively high) strength levels is also comparable to Type 304 in more aqueous environments (Armco, Inc. 1983). Similarly, the normal corrosion resitance of Custom 450 is superior to that of heat treated Type 410 and similar to that of Type 304 (Carpenter Technology 1971). NITRONIC 60 is unique in that it has better corrosion resistance to chloride-induced pitting attack than Type 316 (i.e., an alloy specially formulated for pitting resistance to chlorides) and an outstanding resistance to abrasion by suspended solids and to galling, and cavitation when exposed to aqueous environments (Armco, Inc. 1984a).

PART III: CORROSION AND GALLING

The Problem of Corrosion

9. Selecting a material with inadequate corrosion resistance for a particular application can be an expensive mistake. Direct and indirect economic losses that can result from corrosion include:

<u>a.</u> Failure of equipment and associated damages (e.g., a tainter gate falls because hoisting cable bolts break.)

<u>b.</u> Replacement of equipment.

<u>c.</u> Overdesign to allow for corrosion.

<u>d.</u> Shutdown of equipment.

<u>e.</u> Loss of a product (e.g., if a hydraulic piping system develops a corrosion-induced leak).

<u>f.</u> Contamination of a product.

<u>g.</u> Loss of efficiency (e.g., corrosion products lower heat transfer rates in cooling systems).

10. Some of these indirect losses can cost much more than the difference between a material that would have performed satisfactorily and one that would not. Therefore, it is important to consider potential indirect losses due to corrosion when selecting material.

11. Corrosion can also constitute a significant safety hazard if stress-corrosion cracking occurs in critical parts of transportation media.

12. In addition to these economic and safety aspects, corrosion is also important from the point of view of conserving the earth's supply of materials. The supply of many of the metals and materials used to make conventional steel and low alloy steels is diminishing and these products are being imported into the United States at ever increasing prices.

General Corrosion Behavior, Pitting Attack, and Concentration-Cell Corrosion

13. The excellent corrosion resistance of stainless steels depends on the formation and maintenance of an invisible, passive oxide film on the

exposed surfaces. This allows the stainless steels to exhibit potentials that are more noble (electrically positive) than they would have in the active (corroding) condition. In the passive condition, stainless steels have electrochemical characteristics similar to those of a noble metal such as gold. If this passive film is locally destroyed and cannot be readily repaired, pitting attack can be expected to occur in certain environments (especially, chloride-containing, aqueous environments). Similar localized corrosion in the form of oxygen-differential, concentration-cell corrosion can occur in crevices and under deposits (i.e., in occluded cells) where there is insufficient oxygen to maintain the passive film. The absence of oxygen in occluded cells causes the stainless steel to become electrochemically active (i.e., become anodic) and exhibit a negative potential relative to that area where the passive film is still intact. This form of corrosion can be especially deleterious because it is usually facilitated by a large driving voltage between the passive and active regions and an undesirably large cathode-to-anode area ratio.

14. Significant insight into corrosion behavior can be obtained by analyzing data obtained from anodic polarization tests conducted in a laboratory. In general, stainless steels have very negative primary passivation potentials (E_p) and small critical current densities for passivation (i_c); normally, they passivate quite readily in aerated aqueous environments. Once passivated, the alloys will normally corrode at very low rates in accordance with Faraday's Law and their passive current densities (i_p). If the oxidizing characteristics of the environment are overly powerful, alloys can be spontaneously polarized to potentials sufficiently noble that the alloy will be subjected to accelerated corrosion and pitting attack in the transpassive potential region (i.e., corrode at the high current densities associated with the potentials more noble than the transpassive potential [E_{tp}]). The desirable anodic polarization characteristics for stainless steels are: low values of i_c, very negative values for E_p, low values of i_p, very positive values for E_{tp}, and large potential differences between E_p and E_{tp}.

15. Values of E_p, i_c, i_p, and E_{tp} for selected stainless steels in deaerated, 1N sulfuric acid are included in Table 4 (Segan et al. 1982). Adding chlorides to the test environment reduces the passive potential regions

(i.e., the values of $E_{tp} - E_p$) and increases the magnitudes of i_c and i_p (Segan et al. 1982). Similar adverse phenomena occur, in general, when the temperature of the environment is increased and/or the pH is lowered. The deleterious effects of high operating temperatures, acidic environments, and the presence of chlorides on stainless steels have been verified and explained through laboratory testing. Additional laboratory testing has also shown that all of the stainless steels listed in Table 4 spontaneously passivate in aerated Columbia River water and corrode in the passive potential region at very low uniform corrosion rates (i.e., corrosion rates associated with i_p values of 2.8 to 8.2 x 10^{-7} ampere/cm^2, Segan et al. 1982).

Galvanic Corrosion

16. The initial driving voltage for corrosion of adjacent dissimilar metals can be estimated when a galvanic series exists for the environment of concern. In general, larger driving voltages increase the initial rate of attack to the less noble alloy when dissimilar metals are metallically connected and exposed to a corrosive environment. For example, the galvanic series in Table 5 (Segan et al. 1982) shows that NITRONIC 60 has a potential of -0.327 volt referenced to a saturated calomel electrode (SCE), whereas ASTM A36 steel has a potential of -0.574 volt. If the two alloys were metallically connected and exposed to this environment, NITRONIC 60 (i.e., the alloy with the more positive potential) would be cathodic to the ASTM A36 steel which would be the anode in the corrosion cell. The ASTM A36 steel would experience accelerated galvanic corrosion at an initial driving voltage of 0.247 volt (the potential difference between the two materials). The NITRONIC 60 would, at least in part, be cathodically protected.

17. The data in Table 5 provides insight regarding the mitigation of galvanic corrosion. Materials should be selected so that those which will be metallically connected will have similar potentials in the environment where they will be exposed. Alternatively, the materials can sometimes be electrically isolated from each other. Galvanic corrosion problems can also be reduced by ensuring that the cathodic area is smaller than the anodic area. Large cathode-to-anode area ratios must be avoided if galvanic corrosion is to be avoided. Coatings used in conjunction with cathodic protection have also been effective in mitigating galvanic corrosion.

18. The initial driving voltage for galvanic corrosion will normally decrease with time because of polarization at the anodes and cathodes. This decrease in the driving voltage, in turn, reduces the galvanic corrosion current density at the anodes and lowers their corrosion rates. Table 6 (Segan et al. 1982) lists the galvanic corrosion current densities obtained for equal anodic and cathodic areas of ASTM A36 steel connected to selected grades of stainless steel. Based on these data, galvanic corrosion of ASTM A36 steel is not significantly affected by the chemistry or metallurgical condition of the stainless steel involved. The corrosion current densities for the ASTM A36 steel vary between 1.4 and 2.5 x 10^{-5} ampere/cm^2.

Cavitation

19. Tests conducted in accordance with ASTM G32 have allowed stainless steels and a low-alloy carbon steel to be ranked according to their cavitation resistance (Table 7, Segan et al. 1982). Not unexpectedly, NITRONIC 60 had the best cavitation resistance of the materials evaluated. Similar cavitation resistance results have been obtained for stainless steels exposed to jet-impingement by river water. The relative cavitation depth damages for NITRONIC 60, 17-4PH, Type 316, and CA-6NM were reported as being 1.0, 1.9, 3.7, and 6.6, respectively (Schumacher 1986). These data clearly indicate that cast NITRONIC 60 could be a viable alternative for CA-6NM where cavitation is a concern.

Galling

20. When two metal surfaces are rubbed together under heavy pressure, and without lubrication, it is expected that galling (or even seizing) may result.

21. The "button and block" galling test has been used to evaluate the adhesive wear resistance of various stainless steels under nonlubricated conditions (Schumacher 1977). Specimens were considered galled if deep scoring and heavy surface damage were evident during examination of the surfaces at 10X magnification. The lightest load that caused galling was used to calculate the "threshold galling stress." Threshold galling stresses for

selected stainless steel combinations are included in Table 8 (Schumacher 1977).

22. The data in Table 8 establish that many contacting stainless steel combinations are highly susceptible to galling. Most important, the data show that NITRONIC 60 can be used in contact with many stainless steels without concern for galling. Galling problems associated with the use of Type 304 nuts and bolts could very well be eliminated by fabricating one of the components from NITRONIC 60.

PART IV: CASE STUDIES

23. These case studies present two successful examples which indicate that properly selected, corrosion-resistant stainless steels are viable options for roller assemblies on tractor-type dam gates (such as intake gates) and for dam gate seal materials.

Oahe Dam, Missouri River

24. The first case study demonstrates the successful use of high strength corrosion-resistant "aerospace" stainless steels for tractor-type dam gate components (Komp and Schmitt 1966).

25. Until about 20 years ago, the rollers for tractor-type dam gates (sometimes referred to as intake gates) were conventionally fabricated from Type 410 stainless steel that had been heat treated to the strength level provided by a hardness of 259 to 307 Brinell. The heavier-than-usual hydrostatic loads (over 4,000,000 lb) on the tractor-type gates for Oahe Dam on the Missouri River necessitated the use of either larger Type 410 stainless steel rollers or rollers of increased strength and hardness. During engineering design, it was quickly established that rollers fabricated from Type 410 would be too large, and the desired size rollers could not be fabricated from any martensitic 400-series stainless steel without some undesirable loss in corrosion resistance. Further, there had been some incidents of cracking in rollers fabricated from Type 410. After serious consideration and evaluation of many candidate materials by the design engineers, they selected corrosion-resistant, martensitic, 17-4PH stainless steel for the rollers at Oahe Dam.

26. The rollers were cost-effectively machined from centerless ground bars of solution-heat-treated 17-4PH. Subsequently, the rollers were given a simple, low-temperature, PH heat treatment that developed a hardness of 385 to 418 Brinell (a hardness considerably higher than the specified minimum of 365). Equally significant, there was no need to final machine the rollers. The 17-4PH has excellent resistance to both oxidation/scaling and distortion during the PH heat treatment.

27. Another advantage obtained by selecting 17-4PH for the roller material was that the width of the individual rollers could be reduced more than 25 percent, permitting the use of a narrower track. This overall decrease in roller size allowed a more corrosion-resistant, higher strength stainless steel (compared to Type 410) to be used without an increase in cost.

28. The 17-4PH rollers and their associated Type 304 stainless steel links and pins and 15-7PH Mo stainless steel retaining rings have been in service, both totally immersed and alternately immersed in the Missouri River since their original installation (1962), without corrosion problems. Similar experience has been reported for the roller assemblies on the tractor-type gates at Gavins Point Dam on the Missouri River.

29. Some districts are considering using round link chain and pocket wheels for tainter gate hoists. These may fulfill the required design and cost criteria better than roller chain. If suitability is proven, round link chain will be used exclusively on dams on the Mississippi River during major rehabilitation, in the interest of standardization of gate operating machinery.

Dam Gate Seal Materials

30. The second case study involved an indepth study of the Corps of Engineers' experience with gate seals for 40 dams on the Monongahela, Ohio, Mississippi, Columbia, and Illinois Rivers. Information from this study is significant because it can be useful in selecting the best materials and design options for dam gate seals.

31. Engineer Manual (EM) 1110-2-2702 (Department of the Army, Office of the Chief of Engineers 1966) states that the side seals on tainter gates should be rubber, the side-seal rubbing plates (i.e., the pier seals) should be of a corrosion-resisting steel to ensure permanently smooth surfaces, and the rubber seals should be attached to the gates so as to allow for field adjustment. The same manual also provides guidelines for the bottom seals on these structures. If a small amount of leakage under a closed gate can be tolerated, direct contact between the finished bottom edge of the skinplate and a corrosion-resistant surface on the sill is considered adequate.

However, if a tighter seal is required, it may be necessary to use a rubber seal attached to the skinplate.

32. Examination of the gate seals for the dams included in the study revealed that the guidelines of EM 1110-2-2702 have, in general, been followed with reasonably good performance. The only exception is at Emsworth Dam on the Ohio River where wood was used for seals on the vertical lift gates between 1934 and 1936. They were replaced with rectangular neoprene seals during the major rehabilitation of the dam between 1981 and 1986. Reportedly, personnel at Emsworth Dam do not like rubber seals on the gates because they tend to "bind" and subsequently overload the gate motors. The rubber seals were found to bind in the vertical travel, primarily because the seals are set for the "gate closed" gauge, which over the years has widened due to wear and corrosion, while the gauge of the pier track above the gate closed position is narrower. Rubber seals exhibit a great deal of friction, especially in the dry condition, under even nominal pressure. The problem has been addressed and the solution consists in realigning the lower portion of the pier gate wheels and seal gauge, and providing a relief for the rubber seals above the gate closed elevation. This opinion, however, is not completely shared by personnel at the other dams contacted. For example, nylon-reinforced seals have been used on roller gates for as long as 46 years without the need for replacement (at Dam No. 4 on the Mississippi River). Only about 100 ft of rubber or neoprene J-seals have been replaced on the 15 tainter gates at Dam No. 24 on the Mississippi River during the past 25 years.

33. An unavoidable problem associated with the use of rubber or neoprene seals on the gates is mechanical damage from river debris and ice that collects between the rubber and the seal plates in the piers and spillways. This can be a very serious problem if rubber or neoprene seals are used on the bottom of tainter gates.

34. Based on an analysis of the information collected during this investigation, the most viable materials and design options for the side and bottom seals on tainter dam gates are listed below.

a. Dam Gate Side Seals

(1) Natural rubber or neoprene J-seals for the gates, preferably with fluorocarbon inserts in the seals for the rubbing or contact areas.

(2) Type 304 stainless steel plates for the contacting seal surfaces in the piers.

(3) Type 304 stainless steel bolts and washers with NITRONIC 60 nuts for attachment of the J-seals (to minimize galling or wear and to facilitate removal and loosening of the bolts for field adjustment of the seals).

b. Dam Gate Bottom Seals

(1) Type 304 stainless steel plates attached to the skinplates on the gates.

(2) Type 304 stainless steel plates for the spillway and sills for those gates where water leakage can be tolerated.

(3) Rubber or neoprene wedge seals may be required where leakage cannot be tolerated. See paragraph 33.

PART V: MATERIALS SELECTION

35. The materials applications presented in this report were, in general, obtained from discussions with the U.S. Army Corps of Engineers personnel. Information was also obtained from various guide specifications and as-built drawings.

36. When comparing materials presented in this report for a given application with those in existing drawings and guide specifications, it should be understood that changes have occurred in the ASTM and Federal Specifications since the drawings and specifications were formulated. The known changes (as of July 1985) include:

ASTM A7	Replaced by ASTM A36
ASTM A19	Discontinued
ASTM A59	Replaced by ASTM A689
ASTM A68	Replaced by ASTM A668
ASTM A129	Discontinued
ASTM A232	Discontinued
ASTM A235	Replaced by ASTM A668
ASTM A236	Discontinued
ASTM A237	Replaced by ASTM A668
ASTM A273	Replaced by ASTM A711
ASTM A296	Combined with ASTM A743 and A744
ASTM A298	Discontinued
ASTM A373	Replaced by ASTM A36
ASTM B143	Replaced by ASTM B584
ASTM B144	Replaced by ASTM B584
ASTM B146	Replaced by ASTM B584
QQ-C-806	Replaced by WW-P-405
QQ-S-561	Replaced by QQ-B-154
SS-P-351	Cancelled
WW-P-406	Cancelled
WW-P-491	Cancelled

WW-V-051	Cancelled
WW-V-054	Cancelled

37. The following is a list of suggested materials for components used in Civil Works projects, The materials marked by a bullet (•) are the most recent and preferred options.

Bulkhead & Tainter Gate Components

Skin Plate	ASTM A36 Steel ASTM A441 Steel ASTM A514 Steel
Diagonals	ASTM A36 Steel ASTM A441 Steel ASTM A514 Steel
Horizontal Girders	ASTM A36 Steel ASTM A441 Steel
Trunnion Pins	ASTM A668, Class E Steel Forgings
Trunnion Bushings	ASTM B148 Aluminum Bronze No. C95400
Trunnion Housings	ASTM A27, Grade 65-35 Cast Steel
J-Seals	Natural Rubber* Neoprene*
Bolts for J-Seals	• Type 304 Stainless Steel
Nuts for J-Seals	• Armco NITRONIC 60 Stainless Steel
Trunnion Girders	ASTM A36 Steel ASTM A441 Steel Steel-Reinforced Concrete
Trunnion Yokes	ASTM A27, Grade 65-35 Cast Steel
st Tension Rods for Concrete Trunion Girders	ASTM A94 Steel
Bottom/Embedded Seals	• Type 304 Stainless Steel Lead Babbit
Ropes	• Type 308 Stainless Steel
Rope to Gate Connections	ASTM A27, Grade 65-35 Cast Steel ASTM A36 Steel ASTM A441 Steel ASTM A242 Steel
Wear Plates (under wire ropes)	ASTM A242 Steel ASTM A441 Steel

*Preferably with fluorocarbon inserts for rubbing-contact areas.

Bulkhead & Tainter Gate Components (Continued)

Rope Sockets	• ASTM A276, Type 410 Stainless Steel • Type 302 Stainless Steel
Keeper Plates for J-Seals	• ASTM A276, Type 410 Stainless Steel
J-Seal Heaters	ASTM A53, Schedule 80 Steel Pipe
Trunnion-Hub Pins	ASTM A668, Class H Steel Forgings ASTM A27, Grade 65-35 Cast Steel
Seal Plate on Gate	• Type 304 Stainless Steel
Gate Arms	ASTM A36 Steel ASTM A441 Steel
Side Seal/Embedded	• Type 304 Stainless Steel
Bulkhead	ASTM A441 Steel
Bulkhead Dogging Lever	ASTM A274
Bulkhead Roller	ASTM A148, Grade 120-85, Steel Casting
Bulkhead Collar	ASTM A36 Steel
Bulkhead Bolts	ASTM A307 Steel
Bulkhead Bushings	ASTM B148, Alloy No. C95500
Bulkhead Axle	ASTM A291, Class 5
Bulkhead Lifting Bar	ASTM A148, Grade 150-125 Steel Casting
Wire Rope Adjusting Bolts	ASTM A564, Grade XM25 Stainless Steel • Armco 17-4PH Stainless Steel • Carpenter Custom 450 Stainless Steel
Hoist Bolts	• ASTM A276, Type 410 Stainless Steel • ASTM A276, Type 416 Stainless Steel
Hoist Nuts	• Armco Nitronic 60
Flanged-Spiral Segment	ASTM A36 Steel
Safety Grating	6060-T52 Aluminum Alloy Tubing
Hoist Frame	ASTM A36 Steel
Hoist-chain bars	AISI 3140, class C, ASTM A564 Grade XM-25
Hoist-chain pins	AISI 3340, class C, ASTM A564 Grade XM-25

Bulkhead & Tainter Gate Components (Continued)

Position Indicator Hand	ASTM A167 Stainless Steel • ASTM A276, Type 304 Stainless Steel
Bolts	• ASTM A276, Type 410 Stainless Steel • ASTM A276, Type 416 Stainless Steel
Nuts	• Armco NITRONIC 60 Stainless Steel
Shear Pins	ASTM A434, Class BB
Shims	ASTM A36 Steel
Pinions	ASTM A668, Class G Forgings
Pinion/Hoist	ASTM A291, Class 5

Miter Gate Components

Skin Plate	ASTM A36 Steel ASTM A242 Steel ASTM A441 Steel
Diagonals	ASTM A36 Steel ASTM A514 Steel
Intercostals	ASTM A36 Steel
Diaphragms	ASTM A36 Steel
Horizontal Girders	ASTM A36 Steel
Gudgeon Pins	ASTM A668 Steel Forgings
Gudgeon Bushings	AMPCO 16 Aluminum Bronze
Gudgeon-Pin Hoods	ASTM A36 Steel
Gudgeon Rings	ASTM A36 Steel
Gudgeon-Pin Barrels	ASTM A36 Steel
Link Pins	ASTM A688 Steel Forgings
Anchor Bars	ASTM A36 Steel ASTM A441 Steel
Anchorage Wedge Blocks	ASTM A688 Steel Forgings
Embedded Anchorages	ASTM A36 Steel
Pintle Bushings Sockets	Cast Steel
Pintles	• ASTM A473, Type 303 Stainless Steel* • ASTM A743 and A/44, CF-8 Stainless Steel ASTM A564, Type 630 Stainless Steel**
Pintle Socket Grease Lines	• ASTM A312, Type 304 Stainless Steel Pipe • ASTM A269, Type 316 Stainless Steel Tube High Pressure Neoprene Hose
Pintle Shoes	QQ-S-681, Grade 70-36 Cast Steel ASTM A36 Steel
Pintle Base	• ASTM A27, Grade 60-30 Cast Steel

*Annealed.
**Brinell Hardness of 390 to 410.

Miter Gate Components (Continued)

Pintle Bushings	ASTM A564, Type 630 Stainless Steel* ASTM B148 Aluminum Bronze, Alloy C95400
Miter Contact Blocks	Carpenter 450 Stainless Steel • Armco 17-4PH Stainless Steel ASTM A36 Steel**
Filler Between Miter and Quoin Contact Blocks and End Posts of Miter Gate and Between Contact Blocks and Embedded Steel Wall Retainers	Epoxy such as Nordbak Cast Zinc
Reaction Bar	ASTM A29, Grade 1020 Steel ASTM A29, Grade 1040 Steel
Quoin Contact Blocks	ASTM A27, Grade 70-40 Cast Steel o Armco 17-4PH Stainless Steel ASTM A441 Steel ASTM A36 Steel**
Quoin Contact Block Retainer	ASTM A 36 Steel
Miter Contact Block Retainer	ASTM A36 Steel
Gate Seals/J-Seals	Neoprene+ Natural Rubber+
Sill Plates/Nosings	ASTM A36 Steel • Type 304 Stainless Steel
Mitering Device Guide Rollers	ASTM A148, Grade 80-40 Cast Steel++
Mitering Device Bolts	ASTM A668 Steel Forgings
Mitering Device Bushings	ASTM B584, Alloy C93200
Miscellaneous Bushings	Aluminum Bronze
Bumpers and Fenders	ASTM A36 Steel Low Friction Butyl Rubber White Oak Creosote-Treated Pine

*Brinell Hardness of 270 to 290.
**Preferably with Ceramic/Metal-Filled Epoxy Coating.
+Preferably with fluorocarbon inserts for rubbing-contact areas.
++With provisions for lubrication.

Miter Gate Components (Continued)

Miscellaneous Bearings	Aluminum Bronze
Miscellaneous Bolts/Nuts	ASTM A307 Steel* ASTM A325 Steel* • Type 304 Stainless Steel Bolts** Armco NITRONIC 60 Nuts**
Seal Heater Tubes/Pipes	Type K Copper Tube • Type 304 Stainless Steel Tube ASTM A53, Schedule 80 Steel Pipe
Culvert Valve Piston Rods	QQ-N-286, Monel • Type 410 Stainless Steel • Carpenter Custom 450 Stainless Steel • Type 416 Stainless Steel • Armco 17-4PH Stainless Steel
Miter Gate Casting for Strut-Pin Connection (Machinery)	ASTM A148 Cast Steel
Miter Gate Pin Connection (Machinery)	ASTM A668, Class C Steel Forgings
Bolts for Attaching Castings to Gate	ASTM A325 Steel
Shear Pin Bushing	ASTM A663, Grade 45 Steel

*Where bolts/nuts are not to be removed.
**Where bolts/nuts are to be occasionally removed.

Miter Gate Machinery

Anchor Bolts	ASTM A307 Steel
Angles	ASTM A36 Steel
Base	ASTM A36 Steel
Stud Bolts	ASTM A668 Steel Forgings
Turned Bolts	ASTM A307 Steel ASTM A320, Grade L-7 Steel
Hold-Down Bolts for Cylinder	ASTM A307 Steel
Rack Bumper	ASTM D2000 Rubber
Piston-Rod Bushing	ASTM B584, Alloy 2B
Snubbing Bushing	ASTM A675, Grade 45 Steel
Sector Arm	ASTM A514, Grade F Steel ASTM A441 Steel
Sector Arm Wheel Pin	ASTM A668, Class K Steel Forgings
Sector Arm Bushings and Washers	ASTM B584, Alloy C92300
Sector Arm Support Wheel	ASTM A564, Grade XM-25 Stainless Steel • Armco 17-4PH Stainless Steel • Carpenter Custom 450 Stainless Steel
Cap Screws	ASTM A193, Grade B-3 Stainless Steel • Type 40 Stainless Steel
Sector Base	QQ-S-681, Class 70-36 Cast Steel ASTM A148, Grade 90-60 Cast Steel
Cross Pins	ASTM A668, Class D Steel Forgings ASTM A668, Class K Steel Forgings
Cross Pin Steel Bushings	ASTM A663, Grade 45 Steel
Cylinder Heads	ASTM A148, Grade 80-40 Cast Steel ASTM A27, Grade 60-30 Cast Steel
Hydraulic Cylinder Base	ASTM A36 Steel
Hydraulic Cylinder	ASTM A106, Grade B Steel Pipe*

*With forged flanges.

Miter Gate Machinery (Continued)

Eyebolt for Sector Pin	ASTM A668, Class D Steel Forgings
Fitted Bolts	ASTM A307 Steel
Flanged Spacers	QQ-S-681, Class 65-35 Cast Steel
Strut Follower	QQ-S-681, Class 105-85 Cast Steel
Gate End Castings	QQ-S-681, Class 105-85 Cast Steel
Gate End Seal Retainer	QQ-S-681, Class 65-35 Cast Steel
Gland for Hydraulic Cylinder	ASTM B854 Alloy C92300
Pistons	ASTM A48, Class 40 or Class 50*
Gland for Piston Rod	ASTM B584, Alloy 2B
Key for Hydraulic Cylinders	ASTM A575 and A576, Type 1040 Steel
Key for Piston Rod	ASTM A668, Class B Steel Forgings ASTM A576 and A575 Class 1040 Steel
Spring Steel for Strut	ASTM A689 Steel
Piston Rod Nuts	ASTM A668, Class C Steel Forgings A668, Class B Steel Forgings
Wedge Nuts	QQ-S-681, Class 105-85 Cast Steel
Sector Base Plate	ASTM A36 Steel ASTM A441 Steel
Spring Lock Nut	ASTM A668, Class C Steel Forgings
Sector Gear Pin	ASTM A668, Class A Steel Forgings ASTM A668, Class K Steel Forgings
Sector Top Plate	ASTM A36 Steel
Spacer (Ring)	ASTM B148 Aluminum Bronze, Alloy 9C
Spanner Bolt (for Strut)	ASTM A663, Grade 45 Steel
Spanner Nut (for Strut)	ASTM A668, Class A Steel Forgings ASTM A668, Class B Steel Forgings
Springs	ASTM A125 Steel

*Used in Nashville District

Miter Gate Machinery (Continued)

Spring Cartridge	ASTM A148, Grade 80-40 Cast Steel
Spring Housing (for Strut)	QQ-S-681, Class 65-35 Cast Steel
Spring Rod	ASTM A668, Class C Steel Forgings
Strut Pins	• ASTM A276, Type 416 Stainless Steel ASTM A668, Class D Steel Forgings
Strut Segment Body	ASTM A575 and A576 Steel
Strut Segment Flange	ASTM A181, Grade 2 Steel Forgings
Strut Segment Clevis	QQ-S-681, Class 65-35 Cast Steel
Studs for Sector Base	ASTM A193, Grade B6 Stainless Steel
Stud Bolts	ASTM A307, Grade A Steel
Hydraulic Cylinder for Piston	ASTM A48, Class 50 Cast Iron
Piston Ring for Hydraulic Cylinder	Koppers B-19 Bronze
Piston Rod for Hydraulic Cylinder	ASTM A564, Grade XM-25 Stainless Steel • Armco 17-4PH Stainless Steel ASTM A668, Class B Steel Forgings • Carpenter Custom 450 Stainless Steel

Tainter-Valve Components

Skin Plate	ASTM A36 Steel • Type 304 Stainless Steel Clad for Downstream Face
Structural Members	ASTM A36 Steel
Trunnion Pins	ASTM A668 Steel Forgings
Trunnion-Pin Bushings	AMPCO 16 Aluminum Bronze
Anchorage Beams	ASTM A36 Steel
Seal Bolts	• Type 304 Stainless Steel
Seal Nuts	Armco Nitronic 60 Stainless Steel
J-Seals	Neoprene* Natural Rubber*
Trunnion Housings	ASTM A36 Steel ASTM A148, Grade 80-40 Cast Steel
Embedded Bottom Seals	• Type 304 Stainless Steel
Bottom Seal Plates on Valve	• Type 304 Stainless Steel
Valve Top Seal	Neoprene Natural Rubber
Culvert Valve Liner	• ASTM A276, Type 410 Stainless Steel**
Culvert Vaive Side Seal-Embedded	• ASTM A276, Type 410 Stainless Steel
Culvert Valve Connecting Strut	• ASTM A276, Type 410 Stainless Steel
Tainter-Valve Activating System	
Strut Arm	Schedule 100 Steel Pipe
Bell Crank	ASTM A53, Grade B Steel Pipe
Hydraulic Cylinder	ATSM A668 Steel Forgings
Fittings for Strut Arms and Bell Crank	ASTM A27, Grade 65-35 Cast Steel

*Preferably with fluorocarbon inserts for rubbing-contact areas.
**For high-lift locks.

Tainter-Valve Components

Hydraulic Cylinder	ASTM A668 Steel Forgings
Piston Rods	Type K Monel • Carpenter 450 Stainless Steel • Armco 17-4PH Stainless Steel
Anchorages	ASTM A36 Steel
Bushings	ASTM B148 Aluminum Bronze, Alloy C95400
Pins	ASTM A668 Steel Forgings

Emergency-Gate Machinery

Anchor Bolts for Wire Rope	ASTM A307, Grade A Steel
Anchor Bolt Assembly	ASTM A307, Grade A Steel
Angles	ASTM A36 Steel
Axle	ASTM A668, Class C Steel Forgings
Bearing Block (Roller Bearing)	ASTSM A36 Steel
Bearing Pedestal	ASTM A148, Grade 80-40 Cast Steel
Bearing Stance	ASTM A148, Grade 80-40 Steel
Blind Flange (for Bearing Cover)	ASTM A36 Steel
Shear Bolt	ASTM A663, Grade 75 Steel
Roller Support Bracket	QQ-S-681 Steel Casting
Bull Gear	ASTM A27, Grade 60-30 Steel Casting
Bull Gear Pinion	ASTM A291, Class 4 Steel Forgings
Bull Gear Rim	ASTM A290, Class D Steel Forgings
Sheave Bushing	ASTM B584, Copper Alloy C95500
Sheave Block Wheel Bushings	ASTM B854, Alloy C95500
Carriage Wheel	ASTM A36*
Embedded Roller Track	• ASTM A240, Type 410 Stainless Steel
Drum Plates	ASTM A36 Steel
Drive Link for Indicator	• Type 304 Stainless Steel
Drum Tie Bolt	ASTM A307, Grade A Steel
Machinery Base	ASTM A36 Steel
Spacer/Spool	ASTM A36 Steel
Sheave	ASTM A148, Grade 80-40 Steel Castings ASTM A27, Grade 70-36 Steel Castings

*With Type 304 Stainless Steel Rim.

Emergency-Gate Machinery (Continued)

Cartridge Wheel	ASTM A36 Steel
Rope Separator	• ASTM A743 and A744 CF-8 Stainless Steel
Separator Pins	• ASTM A743 and A744, CF-8 Stainless Steel

<u>Segmental Valve Machinery</u>

Anchor Bolt Assembly	ASTM A307 Steel
Angles	ASTM A36 Steel
Arm for Magnet Mounting Indicator	ASTM B584, Alloy C90500
Base	ASTM A36 Steel
Bearing Bracket	ASTM A148, Class 80-40 Cast Steel
Bell Crank Assembly	
Pipe	Schedule 100 Steel
Bushing	Aluminum Bronze
Forgings	ASTM A668, Class C
Turned Bolts	ASTM A307 Steel • Type 304 Stainless Steel
Hold-Down Bolts for Cylinder	ASTM A307 Steel
Bushings	ASTM B584, Alloy C90500
Cylinder Bracket	ASTM A668, Class C Forgings
Trunnion Bushing	ASTM B584, Alloy C90500
Struts and Clevises	ASTM A27, Grade 70-40 Steel Castings
Hydraulic Cylinder	ASTM A106, Grade 2 Steel Pipe
Cylinder Heads	ASTM A148, Grade 80-40 Cast Steel ASTM A27, Grade 60-30 Steel Castings
Cylinder Rocker and Base	ASTM A441 Steel
Gland for Hydraulic Cylinder	ASTM B584, Alloy C90500
Hinged Bearing	ASTM A27, Grade 70-36 Cast Steel
Selsyn Keys	• Type 304 Stainless Steel
Spindle Nut	ASTM A668, Class H Steel Forgings

Segmental Valve Machinery (Continued)

Spring for Strut	ASTM A689 Steel AISI 5160H Steel
Stop Plates	ASTM B584, Alloy C90500
Strut Spindle	ASTM A148, Grade 90-60 Cast Steel
Pillow Block at Fulcrum	ASTM A148, Grade 90-60 Cast Steel
Pistons	ASTM A48, Class 40 or Class 50*
Piston Rod Hydraulic Cylinder	ASTM A524 Steel Pipe
Piston Rod	• Carpenter Custom 450 Stainless Steel • Armco 17-4PH Stainless Steel
Piston Rod Connecting Casting	ASTM A27, Grade 60-30 Cast Steel
Piston Rod Eyebar	ASTM A27, Grade 70-36 Cast Steel

*Used in Nashville District

Emergency Dam (Wicket Type) Components

Structural Steel	ASTM A36 Steel
Link Chain	Ductile Iron
Dogging Device	• Type 304 Stainless Steel

Gears

Drum	ASTM A290, Type G Steel Forgings
Countershaft	ASTM A290, Type G Steel Forgings
Drum Pinion	ASTM A291, Class 6 Steel Forgings
Pinion for Reducer	ASTM A291, Class 6 Steel Forgings
Intermdiate for Emergency Machinery	ASTM A27, Grade 65-35 Steel Castings
Bull (Rim)	ASTM A290, Class 1 Steel Forgings
Intermediate Gear Rim for Emergency Machinery	ASTM A290, Class G Steel Forgings
Tainter Gate Dogging Device Assembly	Phosphorus Bronze
Worm Gear for Tainter Gate Dogging Device Assembly	• Type 304 Stainless Steel
Bull/Tainter Gate Machinery	ASTM A148, Grade 105-85 Cast Steel
Tainter Gate Machinery Pinion	ASTM A668, Grade G Steel Forgings
Sector Gear for Miter Gate Machinery	ASTM A148, Grade 90-60 Steel Castings
Selsyn Drive for Miter Gate Machinery	ASTM A711 Steel Forgings
Tainter Gate Machinery	ASTM A148, Grade 90-60 Steel Castings

<u>Shafts</u>

Brake Wheel Shaft	AISI 1045 Steel
Countershaft	ASTM A291, Class 5 Steel Forgings ASTM A668, Class F Steel Forgings
Drum for Emergency Gate Assembly	AISI 4140 Steel
Drum for Tainter Gate Machinery	ASTM A293, Class 5 Steel Forgings
Emergency Gate Machinery: Bull Gear Shaft, Intermediate Gear Shaft, Bull Gear Pinion, and Intermediate Gear Pinion	ASTM A291, Class 5 Steel Forgings
Emergency Gate Machinery: Carriage Wheel Shaft	ASTM A291, Class 3 Forgings
Reducer Shaft for Emergency Gate Machinery	AISI 4140 Steel
Miter Gate Machinery: Ring-Spring Mandrell	ASTM A668, Class G Steel Forgings
Emergency Gate Sleeve Shaft	ASTM A291, Class 4 Steel Forgings
Tainter Gate Machinery: Indicator Hand Shaft	ASTM A276, Type 304 Stainless Steel
Bull Gear and Drum Shaft	ASTM A668, Class C Steel Forgings
Emergency Gate Roller Assembly Shaft	Aluminum Bronze, Class 3
Torque Shaft for Tainter Gate Machinery	ASTM A108, Grade 60-40 Steel
Sheave Shaft for Emergency Machinery	ASTM A668, Class C Steel Forgings

Pins

Main Rod and Piston Rod for Valve Machinery	ASTM A668 Steel Forgings, Class K
Latch Pins for Tainter Gate Bulkheads	• ASTM A473, Type 431 Stainless Steel • ASTM A276, Type 410 Stainless Steel
Hinge Pin for Valve Machinery	ASTM A564, Type XM-25 Stainless Steel • Armco 17-4PH Stainless Steel • Carpenter Custom 450 Stainless Steel
Vertical and Horizontal Roller Pins for Miter Gate Machinery	• ASTM A276, Type 410 Stainless Steel

Steel Reinforcements for Concrete

Rods	ASTM A322, Grade 5160 Steel Bars*
Post-Tension Cables	ASTM A416 Steel; Seven-Strand Wire
Bars**	ASTM A29 Steel Bars* ASTM A722 Steel Bars*
Grout (for bars)	Portland Cement with Shrinkage Inhibitor

*Fusion-bonded epoxy coated with seawater service.
**Other than ordinary reinforcement steel.

Hydroelectric Plant Components

Francis Turbine Wheel	• ASTM A743, CA-6NM Stainless Steel
Packing Box Shaft Sleeve	ASTM A276, S21800 Stainless Steel • NITRONIC 60 Stainless Steel
Interior Wicket Gate Grease Pipe	ASTM A53, Grade E and S Steel pipe
Scroll Case	Vinyl Coated Carbon Steel
Intake Gate Hoist Cylinder Piston Rods	• Carpenter 450 Stainless Steel • Armco 17-4PH Stainless Steel
Intake Gate Hoist Cylinder Pipe	• ASTM A312, Type 304 Stainless Steel
Intake Gate Guide Tracks	• ASTM A176, Type 410 Stainless Steel • ASTM A276, Type 304 Stainless Steel ASTM A167, Type 304 Stainless Steel
Wicket Gate Wear Plates	• Type 304 Stainless Steel
Intake Gate Roller Chains	• ASTM A276, Type 410 Stainless Steel ASTM A564, Type 630 Stainless Steel • Carpenter Custom 450 Stainless Steel • ARMCO 17-4PH Stainless Steel
Intake Gate Structure	ASTM A36 Steel
Intake Trashracks	ASTM A36 Steel
Intake Screens	ASTM A36 Steel
Generator Heat Exchanger Tubes	ASTM B111, Alloy C70600
Powerhouse Pipe/Tube	
Up to 125 psig for Generator Cooling, Raw Water Service, Spiral Case Drains, Spiral Case Fills, Draft Tube Drains, Under-watering, Drainage Pump Discharges, Turbine Glands, Water-spray Fire Protection (upstream of deluge valve), and Turbine Air Supply	WW-T-799, Type K Copper Tube for Lines Under 3-Inches (Soldered) ASTM A53 Steel Pipe for Lines 3-Inches and Larger (Welded)

Hydroelectric Plant Components (Continued)

Potable Water, 125 psig	WW-T-799, Type K Copper Tube for Lines Under 3-Inches (Soldered) ASTM A53 Steel Pipe for Lines 3-Inches and Larger (Welded); Galvanized
Waterspray Fire Protection (downstream of deluge valve), up to 150 psig	ASTM A53, Schedule 40 Galvanized Steel Pipe for Lines Less than 3-Inches (Threaded) ASTM A53, Schedule 40 Galvanized Steel Pipe for Lines 3-Inches and Larger (Welded)
Circulating Water for Air Conditioning, up to 125 psig	ASTM A53 Galvanized Steel Pipe for Lines Up to 2.5-Inches (Threaded) ASTM A53 Black Steel Pipe for Lines 2.5-Inches and Larger (Welded)
Building and Roof Drains, Sanitary Drains and Vents, and Water Discharges	ASTM A120 Galvanized Steel Where Exposed (Threaded) WW-P-401 Cast Iron Hub and Spigot Pipe Where Underground
Turbine Vacuum Breaker and Sump Vents	ASTM A120 Black Steel (Welded) Pipe
Battery Room Drains	Polyvinyl Chloride Schedule 80 Pipe Where Exposed Duriron Pipe Where Underground
Pressure Sewage, up to 100 psig	ASTM A53 Black Steel Schedule 80 Pipe Where Exposed WW-P-401 Cast Iron Pipe Where Underground
Piezometer, up to 125 psig	WW-T-799, Type K Copper Tube for Lines Up to 3-Inches
Governor, Lube Oil, Circuit Breaker, and Transformer Oil Up to 150 psig	WW-T-799, Type K Copper Tube

Hydroelectric Plant Components (Continued)

Service Air, Brake Air, Draft Tube Air, Depression Air and Bubbler Air, up to 125 psig	WW-T-799, Type K Copper Tube for Lines Under 3-Inches (Soldered) ASTM A53 Galvanized Steel Pipe for Lines 3-Inches and Larger (Welded)
Governor Air and Nitrogen, up to 600 psig	ASTM A106, Schedule 80 Steel Pipe
Carbon Dioxide	ASTM A53, Galvanized Steel Pipe
Governor Air, up to 1100 psig	• Type 304 Stainless Steel, Schedule 40 Pipe* • Type 316 Stainless Steel, Schedule 40 Pipe*
Hypochlorite	Polyvinyl Chloride Pipe
Floatwells	WW-T-799, Type K Copper Tube for Exposed Lines Under 3-Inches (Soldered) ASTSM A53 Galvanized Steel Pipe for Exposed Lines 3-Inches and Larger (Welded)
Sleeves	ASTM A53 Black Steel Pipe ASTM A120 Black Steel Pipe Polyvinyl Chloride Pipe
Basket Strainer Bodies	ASTM A126, Class B Cast Iron
Basket Strainer Baskets	• Type 304 Stainless Steel
Dielectric Unions	WW-U-531

*With socket-weld joints.

Fisheries

Rearing Ponds	6061-T4 Aluminum Alloy
Directional Jets	Schedule 40 Aluminum Pipe
Exit Screens	6061 Aluminum Alloy 5086 Aluminum Alloy Anodized 5052 Aluminum Alloy
Fish-Handling Equipment (Spawning)	• ASTM A276, Type 304 Stainless Steel

Traveling Fish Screens

Chain Pins	ASTM A276, Type S21800 Stainless Steel • ARMCO NITRONIC 60 Stainless Steel
Bushings	ASTM A564, Type 630 Stainless Steel ASTM A564, Type 631 Stainless Steel • ARMCO 17-4PH Stainless Steel • ARMCO, 17-7PH Stainless Steel
Rollers	Dupont Delrin 500
Pin Link and Roller Link Plates	ANSI B29.4 Epoxy-coated C2162H Chain
Cotter Pins	ASTM A276, Type 302 Stainless Steel
Sprockets	Ultra High Molecular Weight Polymer (e.g., Holstelen Gur No. 413)
Chair Tracks	Ultra High Molecular Weight Polymer (e.g., Holstelen Gur No. 413)
Structural Steel	ASTM A36 Steel
Wire Rope	• RR-W-410, Type 302 Stainless Steel • RR-W-410, Type 304 Stainless Steel
Bolts	• ASTM A193, Type 304 Stainless Steel
Nuts	Armco Nitronic 60 Stainless Steel
Screen	Polyester Monofilament (PET) (e.g., Trevira, Type 930)
Sluice Gates	Cast Iron with Aluminum Bronze Seating Surfaces
Floating Orfice Gates and Weir Gates	• ASTM A276, Type 410 Stainless Steel*

*With stainless steel isolated from structural steel using Oilon Pv80.

Miscellaneous Components

R.O. Slide Gate Piston Rods	ASTM A668 Steel Forgings • ASTSM A276, Type 410 Stainless Steel
Superstructure for Power Houses	ASTM A36 Steel ASTM A441 Steel
Slide Gate Discharge Line for Temperature Control	Cast Iron
Doors	3003-H14 Aluminum Alloy 6063-HT5 Aluminum Alloy
Heating/Ventilating Louvers	6063-T5 Aluminum Alloy 3003-H14 Aluminum Alloy
Handrailings	Aluminum Tube/Pipe
Floating Mooring Bitts Posts	ASTM A106, Grade B Schedule 160 Steel Pipe
Floating Mooring Bitts	ASTM A36 Steel(1) Filament Reinforced Plastic
Grease Lines for Floating Mooring Bitts	High Pressure Neoprene Hose • Type 304 Stainless Steel Pipe/Tube
Rollers for Floating Mooring Bitts	• ASTM A416, Type 410 Stainless Steel • Carpenter 450 Stainless Steel • Armco 17-4PH Stainless Steel
Shafts for Floating Mooring Bitts	ASTM A176, Type 410 Stainless Steel Carpenter 450 Stainless Steel Armco 17-4PH Stainless Steel
Roller Bushings for Floating Mooring Bitts	ASTM B148, Alloy C95500* ASTM B22 Bronze*
Floating Bulkheads	ASTM A36 Steel**
Water Supply Conduit Regulating Gate Hoist Piston Rod for Fishladders	ASTM B164 Monel

*Lubricated.
**Vinyl coated.

Miscellaneous Components (Continued)

Firehose Cabinets	5005-H15 Aluminum Alloy 6061-T6 Aluminum Alloy
Tank Liners for Fish Hauling Trailers	Type 300 Series Stainless Steel
Drain Line for Fish Hauling Trailers	Type 300 Series Stainless Steel
Circulating Water Pipe For Fish Hauling Trailers	Type 300 Series Stainless Steel
Waterstops	Natural Rubber Polyvinyl Chloride
Stainless Steel Wire Rope	RR-W-410, Type 300 Stainless Steel
Wire Rope Sheaves and Drums	• Type 304 Stainless Steel*
Wheel Bushings for Vertical Lift Lock Gates	ASTM B22 Bronze, Alloy C86300**
Axles for Vertical Lift Lock Gates	ASTM A668 Steel Forgings • Carpenter Custom 450 Stainless Steel • Armco 17-4PH Stainless Steel
Cables for Vertical Lift Lock Gates	RR-W-410
Seal Heater Pipe for Vertical Lift Lock Gates	• Type 304 Stainless Steel
Wheels for Vertical Lift Lock Gates	ASTM A441 Steel+
Bolts for Vertical Lift Lock Gates	• Type 304 Stainless Steel • Type 410 Stainless Steel
Nuts for Vertical Lift Gates	Armco NITRONIC 60 Stainless Steel

*For wet locations. Carbon steel drums should be coated with Elastuff 504.
**Avoiding the use of Lubrite.
+Brinell hardness of 200 to 215.

Miscellaneous Components (Continued)

Shafts for Deep Well Drainage Pumps	• Type 303 Stainless Steel • Type 416 Stainless Steel
Impellers for Sewage Pumps	Bronze
Fasteners for Sewage Pumps	• Type 304 Stainless Steel
Casings for Water Pumps	Cast Iron
Shafts for Water Pumps	• Type 416 Stainless Steel
Impellers for Water Pumps	Bronze

PART VI: CONCLUSIONS

38. Typical mechanical property data have been presented for 14 stainless steels that are becoming more available for Civil Works applications: the wrought austenitic alloys NITRONIC 60 and Types 302, 303, 304, 308, and 316; the wrought martensitic alloys Types 410, 416, and 431; the wrought martensitic PH (precipitation-hardening) alloys 17-4PH and Custom 450; the wrought semiaustenitic PH alloy 17-7PH; the cast martensitic alloy CA-6NM; and the cast austenitic-ferritic alloy CF-8.

39. While stainless steels are viable options for many lock, dam, and hydroelectric plant applications, no single stainless steel available exhibits the desired mechanical properties and corrosion resistance for all applications. Alloys must be carefully selected and specified for a particular application, and the components must be properly designed and fabricated. General guidelines for selection of materials for specific components are provided in Part V.

Table 1

Corrosion Behavior of Carbon Steel and Stainless Steels*

Material	General Corrosion Rate, mpy**	Pit Depth, mils	
		Max.	Avg.
Carbon Steel	1.2	55	42
Type 410 Stainless	+	27	16
Type 302 Stainless	0	0	0

*Based on 8 years of exposure to Mississippi River water at Winfield, MO.
**Mpy is mils (thousandths of an inch) per year.
+Loss was totally due to pitting attack.

Table 2

Nominal Compositions of Stainless Steels for Lock, Dam, and Hydroelectric Plant Applications*

Alloy	Cr	Ni	C**	Mn**	Si**	P**	S**	Fe	Other
302	17.00-19.00	8.00-10.00	0.15	2.00	1.00	0.045	0.030	Bal.	
303	17.00-19.00	8.00-10.00	0.15	2.00	1.00	0.20	0.15	Bal.	.060 Mo (optional)
304	18.00-20.00	8.00-10.50	0.08	2.00	1.00	0.045	0.030	Bal.	
308	19.00-21.00	10.00-12.00	0.08	2.00	1.00	0.045	0.030	Bal.	
316	16.00-18.00	10.00-14.00	0.08	2.00	1.00	0.045	0.030	Bal.	2.00-3.00 Mo
NITRO (NIC 60)	16.00-18.00	8.00-9.00	0.10	7.00-9.00	3.50-4.50			Bal.	0.08-0.18 N
410	11.50-13.50	-	0.15	1.00	1.00	0.040	0.030	Bal.	
416	12.00-14.00	-	0.15	1.25	1.00	0.060	0.15***	Bal.	0.60 Mo (optional)
431	15.00-17.00	1.25-2.50	0.20	1.00	1.00	0.040	0.030	Bal.	
17-4pH	15.00-17.50	3.00-5.00	0.07	1.00	1.00	0.040	0.030	Bal.	3.00-5.00 Cu; 0.15-0.45 Nb + Ta
CUSTOM 450	14.00-16.00	5.00-10.00	0.05	1.00	1.00	0.030	0.030	Bal.	0.50-1.00 Cu; 1.25-1.75 Cu; 8xC (min) Nb
17-7pH	16.00-18.00	6.50-7.75	0.09	1.00	1.00	0.040	0.030	Bal.	0.75-1.50 Al
CA-6NM	11.50-14.00	3.50-4.50	0.06	1.00	1.00	0.040	0.030	Bal.	0.40-1.00 Mo
CF-8	18.00-21.00	8.00-11.00	0.08	1.50	2.00	0.040	0.040	Bal.	

*Values expressed in weight percent.
**Maximum value except where otherwise noted.
***Minimum.

Table 3

Typical Mechanical Property Data for Stainless Steel

Alloy	Form	Condition	UTS (ksi)	0.2% YS (ksi)	% E	% RA	Hard.	Impact Strength (ft-lbs)
302	Bar	Annealed	85	35	60	70	Bhn 150	Izod 110
	Plate	Annealed	90	35	60	70	Rb 80	Izod 110
	Wire	Annealed	90	35	60	70	Rb 83	Izod 110
303	Bar	Annealed	90	35	50	55	Bhn 160	Izod 80
304	Bar	Annealed	85	35	60	71	Bhn 149	Izod 110
	Tube	Annealed	85	35	50	71	Rb 80	Izod 110
	Plate	Annealed	82	35	60	71	Bhn 145	Izod 110
308	Bar	Annealed	85	30	55	65	Rb 80	Izod 110
	Wire**	Annealed	95	60	50	-	-	Izod 110
316	Bar	Annealed	80	30	60	70	Rb 78	Izod 110
	Tube	Annealed	85	35	50	70	Rb 79	Izod 110
NITRONIC 60	Bar	Annealed	103	60	64	74	Rb 95	Charpy 240
		10% CD	120	91	51	68	Rc 24	-
		40% CD	195	153	20	57	Rc 38	-

*UTS = Ultimate Tensile Strength, YS = Yield Strength, E = Elongation, RA = Reduction in Area, Bhn = Brinell Hardness Number, Rb = Rockwell B Hardness, Rc = Rockwell C Hardness, CD = Cold Drawn, SA = Solution Annealed, WQ = Water Quenched, AC = Air Cooled; OQ = Oil Quenched. Those associated with 17-4 PH and 17-7 PH refer to special conditions developed by Armco, Inc.
**Soft temper.

(Continued) (Sheet 1 of 3)

Table 3 (Continued)

Alloy	Form	Condition	UTS (ksi)	0.2% YS (ksi)	% E	% RA	Hard.	Impact Strength (ft-lbs)
410	Bar	Annealed	75	40	35	68	Rb 82	Izod 85
		QQ + 1 hr/300°F	195	150	15	55	Bhn 390	Izod 35
		QQ + 1 hr/1100°F	125	100	22	65	Bhn 262	Izod 35
	Plate	Annealed	70	35	30	68	Bhn 150	Izod 85
416	Bar	Annealed	75	40	30	60	Rb 82	Izod 20-64
		QQ + 1 hr/300°F	195	150	10	40	Rc 41	Izod 20
		QQ + 1 hr/1100°F	125	100	17	53	Rc 26	Izod 28
431	Bar	Annealed	125	95	20	55	Bhn 260	Izod 50
		QQ + 1 hr/500°F	198	149	16	55	Bhn 415	Izod 40
		QQ + 1 hr/1100°F	140	115	19	57	Bhn 302	Izod 48
17-4 PH	Bar	A	147	130	18	59	Rc 34	Charpy 47
		H900	200	185	14	50	Rc 44	Charpy 15
		H1025	170	165	15	56	Rc 38	Charpy 35
		H1075	165	150	16	58	Rc 36	Charpy 40
		H1100	150	135	17	58	Rc 35	Charpy 45
	Bar	H1150	145	125	19	60	Rc 33	Charpy 50
CUSTOM 450	Bar	SA	141	118	13	50	Rc 28	Charpy 95
		Aged at 850°F***	196	186	14	54	Rc 44	Charpy 20
		Aged at 900°F	195	186	14	55	Rc 42	Charpy 41
		Aged at 1000°F	173	169	17	63	Rc 39	Charpy 51
		Aged at 1150°F	142	91	23	69	Rc 28	Charpy 97

***Aging time of 4 hrs for all temperatures.

(Continued)

(Sheet 2 of 3)

Table 3 (Continued)

Alloy	Form	Condition	UTS (ksi)	0.2% YS (ksi)	% E	% RA	Hard.	Impact Strength (ft-lbs)
17-7 PH	Bar	RH950	185	150	6	10	Rc 41	-
		TH1050	170	140	6	25	Rc 38	-
CF-8	Cast	WQ from above 1400°F	77	37	55	-	Bhn 140	Charpy 74++
CA-6NM	Cast	AC from above 1750; tempered at 1100°F	120	100	24	60	Bhn 269	Charpy 70

++Charpy keyhole notch; all other Charpy impact data are for V-notch.

(Sheet 3 of 3)

Note: All of the above are more cavitation resistant than cast iron or structural steel.

Table 4

Values for the Currents in Selected Stainless Steels*

Stainless Steel/Condition**	E_p, Volt vs. SCE***	i_c, amp/cm^2	i_p, amp/cm^2	E_{tp}, Volt vs. SCE
Type 304, Annealed + 10% CW	-0.347	4.28 10^{-4}	3.27 X 10^{-6}	+0.89
Type 410/Annealed	-0.376	1.49 X 10^{-2}	5.27 X 10^{-6}	+0.81
Custom 450/SA	-0.256	3.68 X 10^{-5}	1.92 X 10^{-6}	+0.92
Custom 450/Aged at 1150°F	-0.277	2.63 X 10^{-5}	2.00 X 10^{-6}	+0.87
17-4PH/Condition A	-0.269	1.60 X 10^{-4}	2.02 X 10^{-6}	+0.89
17-4PH/H1150	-0.312	8.75 X 10^{-5}	2.53 X 10^{-6}	+0.88
NITRONIC 60/Annealed	-0.346	3.63 X 10^{-4}	1.58 X 10^{-6}	+0.92

*E_p = passivation potential, i_c = xriticl current density for passivation, i_p = passive current density, and E_{tp} = transpassive potential

**See Table 3 for condition abbreviations. All samples are deaerated IN sulfuric acid at ambient temperature.

***Saturated calomel electrode.

Table 5

Galvanic Series for Selected Alloys

Alloy/Condition*	Potential, Volt vs. SCE **	Initial Driving Voltage of Alloy Coupled to A36 Steel, Volt
NITRONIC 60/Annealed	-0.327	0.247
Type 304/Annealed + 10% CW	-0.328	0.246
Custom 450/SA	-0.330	0.244
Custom 450/Aged at 1150°F	-0.362	0.212
17-4PH/H1150	-0.384	0.190
17-4PH/Condition A	-0.396	0.178
Type 410/Annealed	-0.488	0.086
ASTM A36/Normalized	-0.574	0.000

*See Table 3 for condition abbreviations. All samples are 0.5 M sodium chloride solution at ambient temperature.

**Saturated calomel electrode.

Table 6

Galvanic Corrosion Current Densities for ASTM A36 Steel When Metallically Connected to an Equal Area of Stainless Steel

Stainless Steel Condition*	Galvanic Corrosion Current Density for A36 Steel, ampere/cm^2
NITRONIC 60/Annealed	1.4×10^{-5}
Type 304/Annealed + 10% CW	2.1×10^{-5}
Custom 450/SA	2.0×10^{-5}
Custom 450/Aged at 1150°F	1.6×10^{-5}
17-4PH/H1150	1.9×10^{-5}
17-4PH/Condition A	2.2×10^{-5}
Type 410/Annealed	2.5×10^{-5}

*See Table 3 for condition abbreviations. All samples exposed to aerated 0.5M sodium chloride solution at ambient temperature.

Table 7

Ranking of Stainless Steels Compared to a Low-Alloy Carbon Steel*

Ranking	Stainless Steel/Condition**	Brinell Hardness No.	Erosion Rate, inch/year
1	NITRONIC 60/Annealed	201	0.4
2	17-4PH/H1150	388	1.2
3	Custom 450/Aged at 1150°F	320	1.3
4	17-4PH/Condition A	321	1.6
5	Type 304/Annealed + 10% CW	197	1.7
6	Custom 450/SA	270	1.9
7	AISI 4130 Steel/Normalized	286	2.5
8	Type 410/Annealed	223	3.8

*Based on cavitation resistance according to ASTM G32 testing.
**See Table 3 for condition abbreviations.

Table 8

Threshold Galling Stresses (ksi) for Stainless Steels*

Block Material	Button Material and Threshold Galling Stress, psi						
	Type 410	Type 416	Type 303	Type 304	Type 316	17-4PH	NITRONIC 60
Type 410**	3	4	4	2	2	3	50+***
Type 416‡	4	13	9	24	42	2	50+
Type 303‡‡	4	9	2	2	3	3	50+
Type 304‡‡‡	2	24	2	2	2	2	50+
Type 316§	2	42	3	2	2	2	38
17-4PH§§	3	2	2	2	2	2	50+
NITRONIC 60§§§	50+	50+	50+	50+	38	50+	50

*Results in psi based on "Button and Block" galling tests.

**Hardened and stress relieved to Bhn 352.

***50+ indicates that no galling occurred at 50,000 psi.

‡Hardened and stress relieved to Bhn 342.

‡‡Annealed to Bhn 140.

‡‡‡Annealed to Bhn 150.

§Annealed to Bhn 150.

§§Condition RH950 to Bhn 415.

§§§Annealed to Bhn 205.

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POINT OF CONTACT: Dr. Ashok Kumar

Phone No.: 217-373-7235
217-352-6511, ext. 235

Address: Commander and Director
U.S. Army Construction Engineering
Research Laboratory
ATTN: USA-CECER-EM, Dr. Ashok Kumar
P.O. Box 4005
Champaign, Illinois 61820-1305